Development of Mid-Frequency Multibeam Sonar for Fisheries Applications

John K. Horne
University of Washington, School of Aquatic and Fishery Sciences
Box 355020
Seattle, WA 98195
phone: (206) 221-6890 fax: (206) 221-6939 email: jhorne@u.washington.edu

Christopher D. Jones and Mike A. Wolfson
Applied Physics Laboratory, University of Washington
Seattle, WA 98105-6698
phone: (206) 543-1615 fax: (205) 543-6785 email: cjones@apl.washington.edu
wolfson@apl.washington.edu

LONG-TERM GOALS

The long-term goal of this program is to investigate the utility of mid-frequency (~10 kHz) acoustics to detect, enumerate, and identify pelagic fish distributions.

OBJECTIVES

Objectives of this research include: comparisons of fish backscatter models, models of mid frequency sound propagation, development of a mid-frequency multibeam sonar, and backscatter measurements using splitbeam echosounders and the multibeam sonar.

APPROACH

Our strategy integrates biological and physical model predictions with field measurements and will combine results in computer visualizations and animations. Efforts are directed in three primary areas: sound propagation modeling, fish backscatter modeling, and mid-frequency multibeam development and field measurements.

Sound propagation modeling efforts focus on continental shelf environments in the northeast Pacific including the Gulf of Alaska and along the Washington coast. Effects of multi-path propagation, water depth, substrate type, substrate and surface roughness, and range dependence on propagation, including temporal and spatial variability in the environment will be modeled.

Sound propagation characteristics will be combined with anatomical models of fish to examine backscatter from individuals and aggregations of fish. This approach will enable us to model potential detection strategies for different types of fish, their behaviors, and to predict variability in fish aggregation backscatter. Backscatter predictions for individuals within aggregations (i.e. the forward problem) will be compared to *in situ* measurements.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Development of Mid-Frequency Multibeam Sonar for Fisheries Applications**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,School of Aquatic and Fishery Sciences,Box 355020,Seattle,WA,98195**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

To measure synoptic distributions of fish schools we will collect mid (10 kHz) and high (38 kHz) backscatter data from fish aggregations using a multibeam sonar and a splitbeam echosounder. The sonar is expected to detect fish at kilometer scale ranges while the echosounder will be used to detect aggregations and individual animals at ranges of hundreds of meters.

WORK COMPLETED

The mid-frequency sound propagation modeling effort focused on the effect of the acoustic waveguide on echo returns from fish schools. The approach examines how reverberation from fish might be masked by reverberation from the bottom or the surface. A full-wave acoustic propagation model was modified to perform sensitivity studies of multi-paths in acoustic waveguide environments. Simulations have used different source depths, water depth, and different bottom types.

To increase understanding of the interaction between sound propagation and the reflection of sound by biological targets, a computer simulation application was developed to visualize individual and group backscatter from known populations of fish.

The design and fabrication of the Pelagic Imaging Mid-frequency Multibeam Sonar (PIMMS) system was completed in summer 2006. Initial testing and calibration of the PIMMS occurred at the APL acoustic calibration facilty in July 2006. The first gear trials were conducted in the Gulf of Alaska from August 11 to August 13 aboard the NOAA RV Miller Freeman. Four sampling stations were occupied in the Chiniak trough for a total data collection time of approximately 20 hours. Deployments of a side-looking, 38 kHz echosounder and midwater trawls were also conducted to provide backscatter and target verification data for comparison to the sonar data.

Storing all laboratory, field, and modeling data in a central location will now be possible with a new data stacker. A 2.9 Tb RAID 6 array has been assembled and integrated into the UW Fisheries Acoustics Research Laboratory LAN. Access for all cooperating researchers will be permitted through a virtual private network (i.e. VPN) and firewall.

RESULTS

Sound propagation modeling has tested bottom types from soft clay and silt to gravel and rock. The model solves for the Green's function from the source to a target (single fish as a point source) located at all ranges and depths set in the simulation. As an illustrative example, consider a silt bottom, a constant bottom depth of 90 m, and a source at 50 m. Figure 1a shows the transmission loss for this waveguide for a 10 kHz carrier frequency. Most of the energy interacting with the bottom penetrates and is absorbed, and the resulting transmission loss field plot is nearly a perfect Lloyd mirror pattern. Modal interference is possible near the surface and near the bottom at greater ranges. Interference can bias echo returns from biological targets. Figure 1b illustrates the bias estimate map showing potential error in estimating biomass from a PIMS reception. The potential maximum bias at a given range over all depths is less than 10 dB, and is well concentrated toward the surface and bottom for water depths deeper than about 80 m.
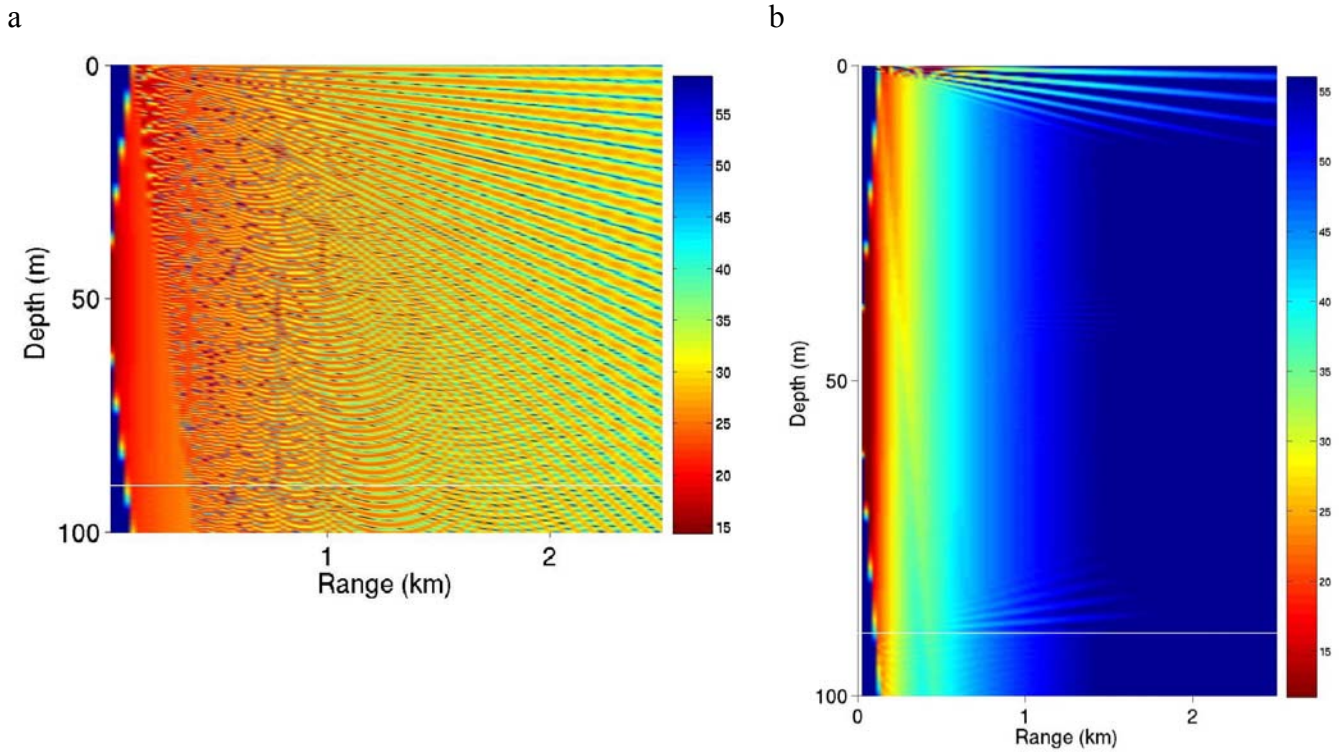
Figure 1. a) Transmission loss field plot using 10 kHz source at a depth of 50 m in a 90 m water column (white line) with a soft silt bottom, b) Bias map derived from the source and environment.

Ensemble and individual acoustic reflectivity (i.e. backscatter) from fish within an acoustic beam can now be visualized and tracked in a single computer application (Fig. 2). In the fish school echogram visualization the position of each fish is calculated for every animal in the model domain and the orientation is extracted for those within the user-defined, acoustic beam. The corresponding backscatter is extracted from a Kirchhoff-ray mode predicted backscatter matrix indexed using pitch, yaw, and roll orientations, and then the fish is rendered in the main panel to match its backscatter intensity (i.e. target strength). Backscatter from all fish within the beam is integrated and plotted on a real-time echogram. Initial work on extinction coefficients is depicted in a second echogram to illustrate the effects of packing density and shadowing on ensemble backscatter. Two fish can be tagged to track individual target strengths at the same or two additional acoustic frequencies. The difference between backscatter intensities (i.e. target strength differencing) is plotted to illustrate potential fish size or species discrimination.
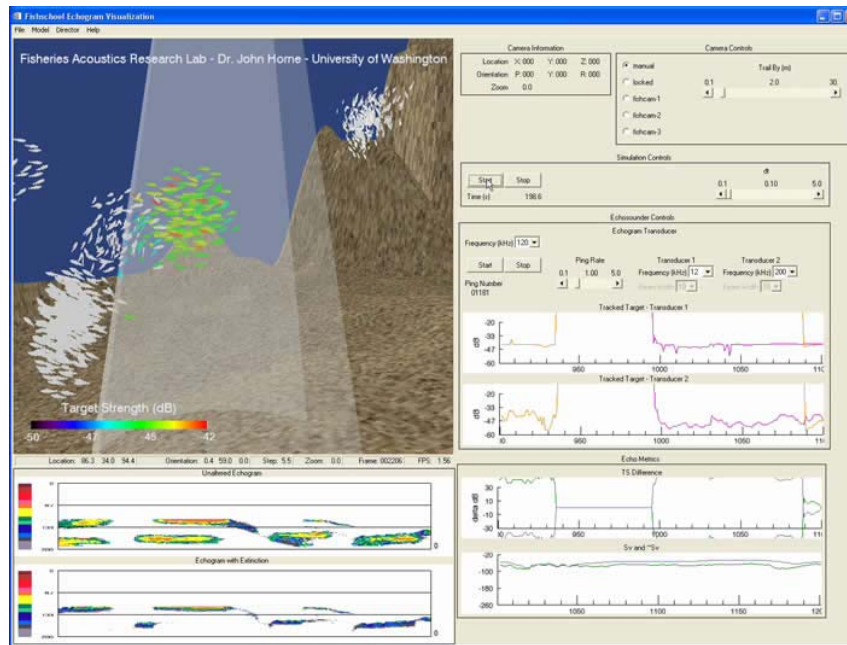
Figure 2. Screenshot of the fishschool echogram visualization application. Fish in the acoustic beam are colored coded for target strength depending on their size, orientation, and position in beam. Integrated energy is displayed in echograms below the main visualization panel. Transducer frequencies are controlled from the upper right boxes. Two fish can be tagged and their target strengths can be tracked (lower right graphs).

The PIMMS system is approximately 1.5 m in diameter and is deployed from a standard CTD winch and cable. The system consists of a circular receiving array (64 data channels, ~5o resolution over 360o) and a separate transmitting line array (16 elements). The resulting transmit beam configuration is 9 degrees vertical and 360o horizontal. The vertical imaging resolution of the system is defined by the intersection of the receiver and transmitter beams (Fig. 3). The receiver simultaneously records all 64 dipole receiving elements and stores the data internally. The data acquisition control processor runs Linux and communicates to the top-side controller (laptop) via 10baseT Ethernet.
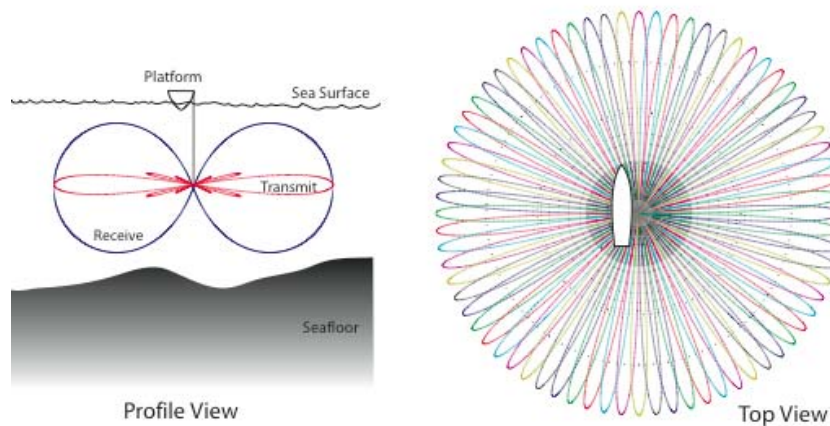

Figure 3: Geometry and imaging volume of PIMMS illustrating the transmit and receive beam patterns.

The transmitter is a custom design 8 channel pulse width modulation (PWM) design capable of generating arbitrary transmit signals on 8 channels which enables transmit beam steering. Vertical imaging resolution is achieved by steering the narrow transmit beam in elevation or by moving the whole system up and down through the water column like a profiler (Fig. 4).

Figure 4. The Pelagic Imaging Mid-frequency Multibeam Sonar (PIMMS) being deployed.

Preliminary analysis of acoustic data taken in August 2006 shows the detection of potential fish aggregations at horizontal ranges up to 300 meters from the ship. Figure 5 illustrates beamformed
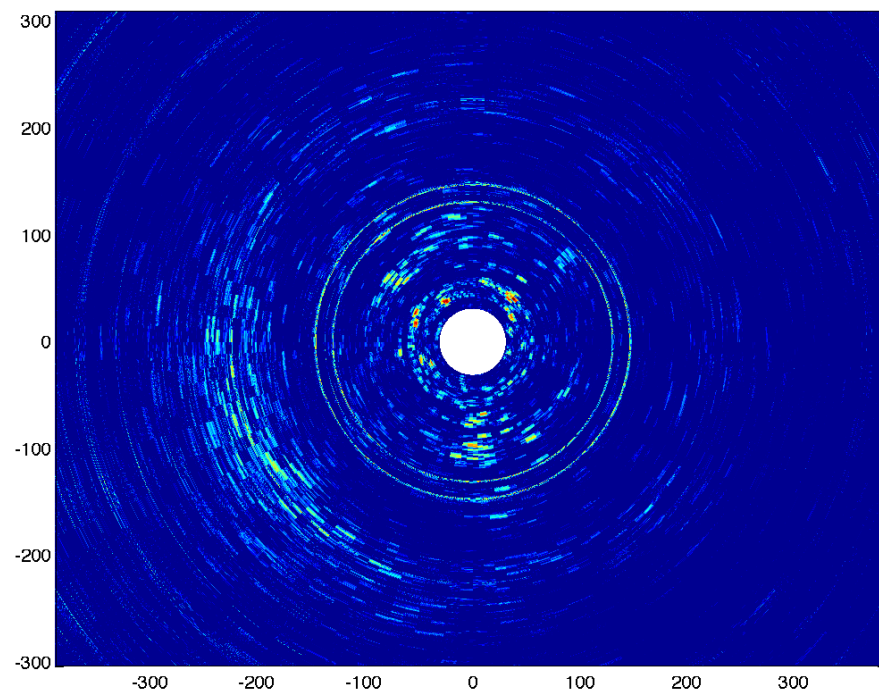
Figure 5. PIMMS image of potential fish aggregations in the Gulf of Alaska.
The water depth at this location was 100 meters.

backscatter from the water column created from a single PIMMS ping, with ~5 degree horizontal beams combined to image a 360o sector. PIMMS is located at the center of the radial image. Backscatter intensities increase from blue to red.

Figure 6 illustrates a closeup view of backscatter targets within a 100 m range of the sonar. Aggregation diameters are approximately 10 meters or less in the horizontal scale. Beyond 100 m, targets are not as well resolved, although they are believed to be fish aggregations. This degredation in backscatter imagery as a function of range is expected and further data analysis to recover longer range targets is ongoing. Several techniques are being employed to recover long range data including high reslution beamforming, the use of longer frequency modulated (LFM) pulses which improves the signal to noise ratio in the waveguide backscatter, the use of matched filtering methods, and modeling waveguide backscatter to better understand the limitation of horizontal imaging in a waveguide.
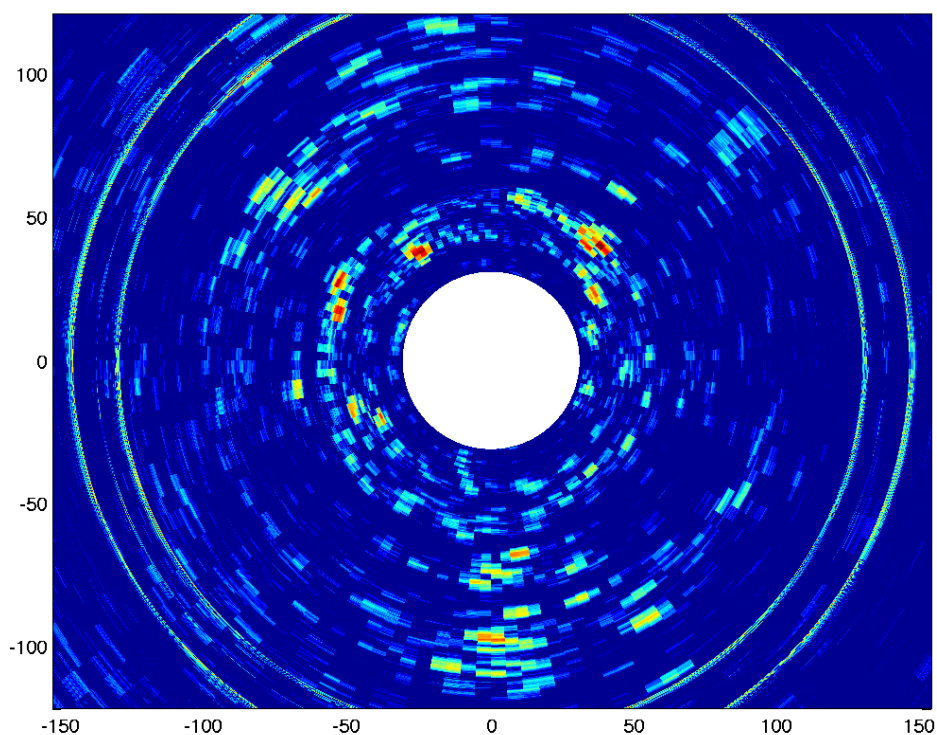

Figure 6. Closeup of PIMMS image of potential fish aggregations in the Gulf of Alaska showing higher image resolution for backscatter targets within a 100 meters radius of the sonar. The sonar is located at the center of the image.

IMPACT/APPLICATIONS

Greater range from an imaging sonar provides synoptic views for fish aggregation distributions during quantitative assessment surveys. This instrument may be used in conjunction with quantitative echosounders or in a moored deployment as part of an ocean observing system.

RELATED PROJECTS

The multibeam sonar developed in this project was also deployed in the in the mid-Atlantic Bight in support of the NOPP sponsored project entitled, "Novel Acoustic Techniques to Measure Schooling in Pelagic Fish in the Context of an Operational Coastal Ocean Observatory."

AWARDS

John K. Horne, University of Washington, H. Medwin prize in Acoustical Oceanography, Acoustical Society of America.